# CSE 417
# Algorithms and Complexity

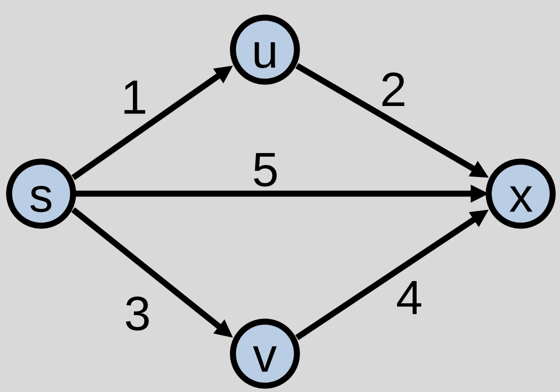
Autumn 2024
Lecture 11
Dijkstra's algorithm

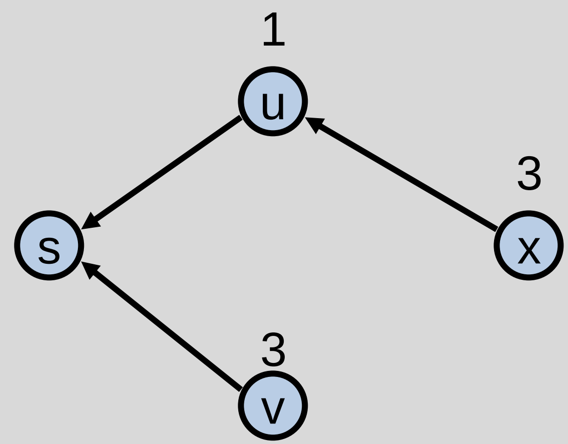
# Announcements

- Topics
  - Dijkstra's Algorithm (Section 4.4)
    - Algorithm and why it works
  - Next Week: Minimum Spanning Trees
- Reading
  - 4.4, 4.5, 4.7, 4.9
- Midterm: Friday, November 1, in class

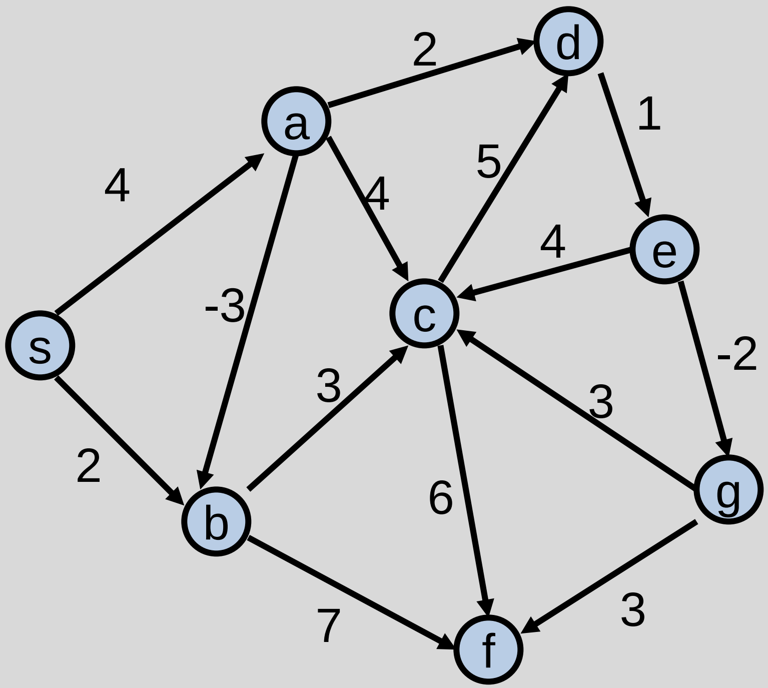
# Single Source Shortest Path Problem

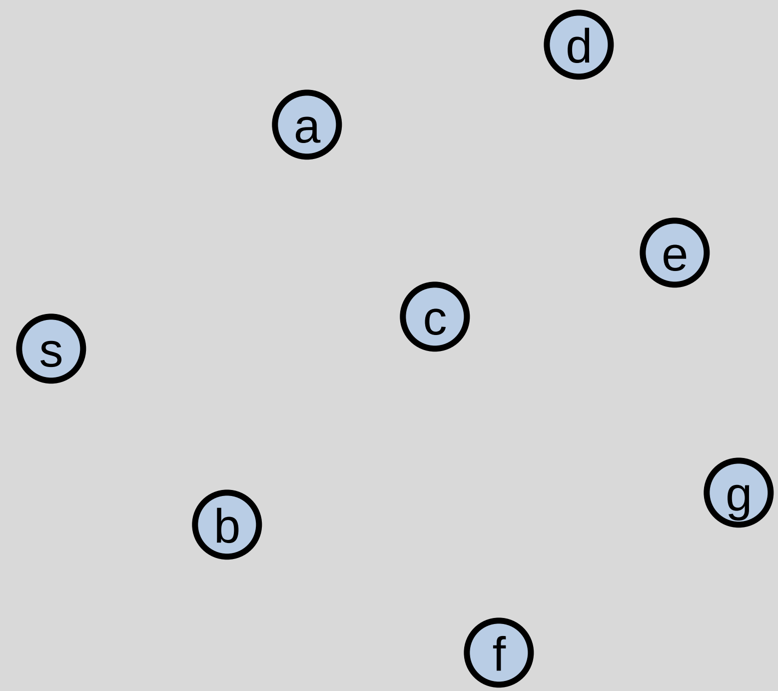
- Given a graph and a start vertex s
  - Determine distance of every vertex from s
  - Identify shortest paths to each vertex
    - Express concisely as a “shortest paths tree”
    - Each vertex has a pointer to a predecessor on shortest path



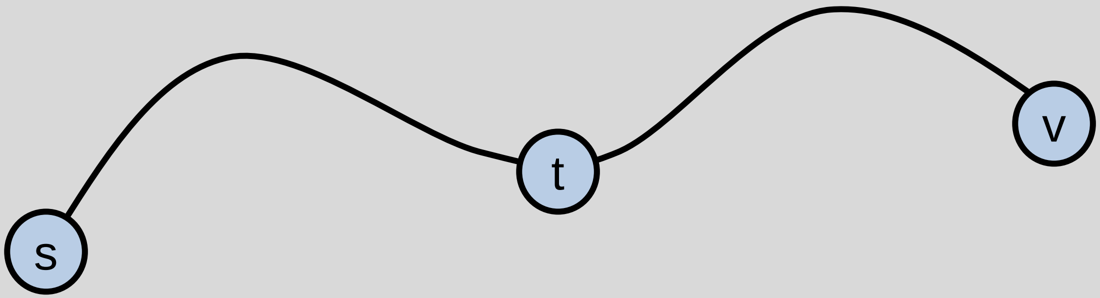
# Construct Shortest Path Tree from s



# Warmup

- If P is a shortest path from s to v, and if t is on the path P, the segment from s to t is a shortest path between s and t




- WHY?

Assume all edges have non-negative cost

# Dijkstra's Algorithm

S = { }; d[s] = 0; d[v] = infinity for v != s

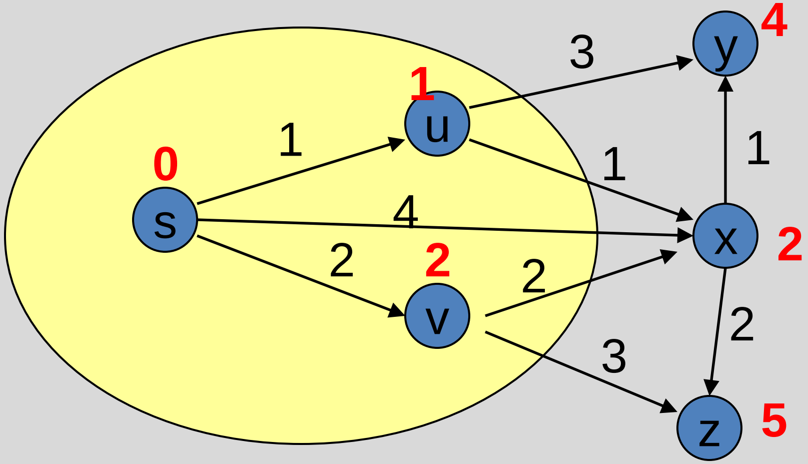
While S != V

Choose v in V-S with minimum d[v]

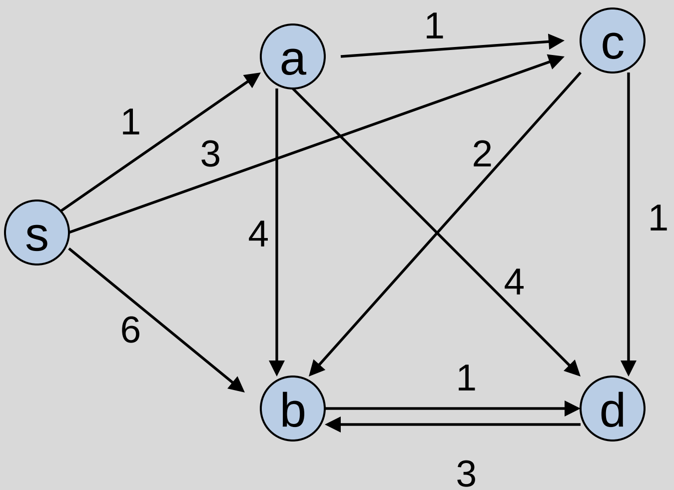
Add v to S

For each w in the neighborhood of v

d[w] = min(d[w], d[v] + c(v, w))



# Simulate Dijkstra's algorithm (starting from s) on the graph



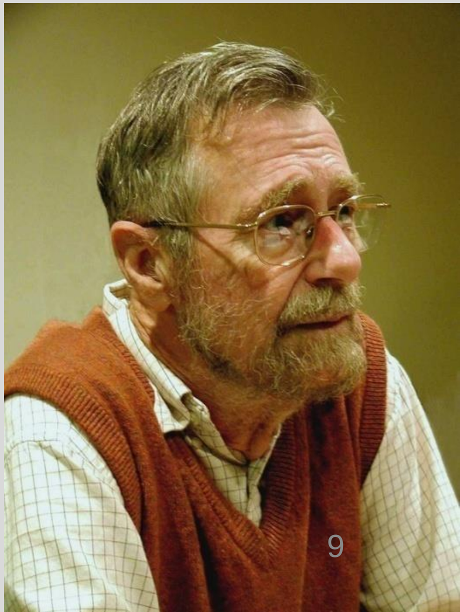

| Round | Vertex Added | s | a | b | c | d |
|---|---|---|---|---|---|---|
| | | | | | | |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |

# Who was Dijkstra?

- What were his major contributions?

# http://www.cs.utexas.edu/users/EWD/

- Edsger Wybe Dijkstra was one of the most influential members of computing science's founding generation. Among the domains in which his scientific contributions are fundamental are
  - algorithm design
  - programming languages
  - program design
  - operating systems
  - distributed processing
  - formal specification and verification
  - design of mathematical arguments

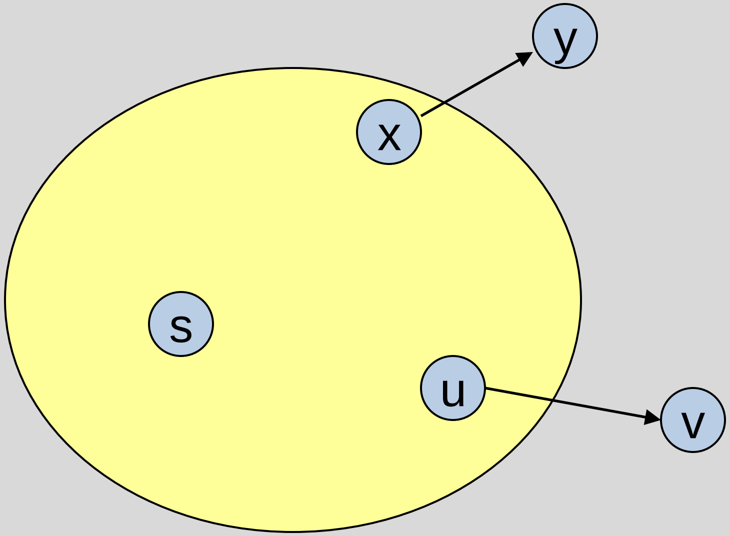


# Dijkstra’s Algorithm as a greedy algorithm

- Elements committed to the solution by order of minimum distance

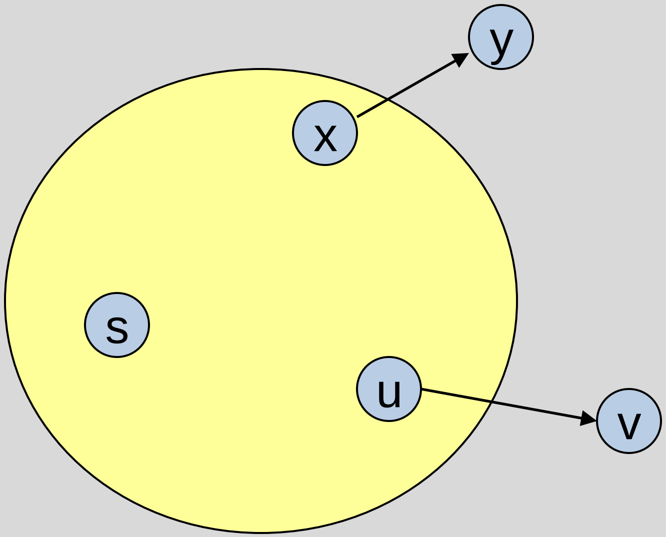
# Correctness Proof

- Elements in S have the correct label
- Key to proof: when v is added to S, it has the correct distance label.



# Proof

- Let v be a vertex in V-S with minimum d[v]
- Let $P_v$ be a path of length d[v], with an edge (u,v)
- Let P be some other path to v. Suppose P first leaves S on the edge (x, y)
  - $P = P_{sx} + c(x,y) + P_{yv}$
  - $Len(P_{sx}) + c(x,y) \geq d[y]$
  - $Len(P_{yv}) \geq 0$
  - $Len(P) \geq d[y] + 0 \geq d[v]$



# Negative Cost Edges

- Draw a small example a negative cost edge and show that Dijkstra's algorithm fails on this example

# Dijkstra Implementation

```
S = { };    d[s] = 0;     d[v] = infinity for v != s
While S != V
            Choose v in V-S with minimum d[v]
            Add v to S
            For each  w in the neighborhood of v
                        d[w] = min(d[w], d[v] + c(v, w))
```

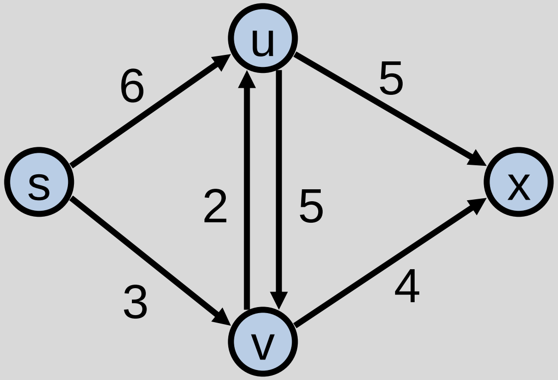
- Basic implementation requires Heap for tracking the distance values
- Run time O(m log n)

# O($n^2$) Implementation for Dense Graphs

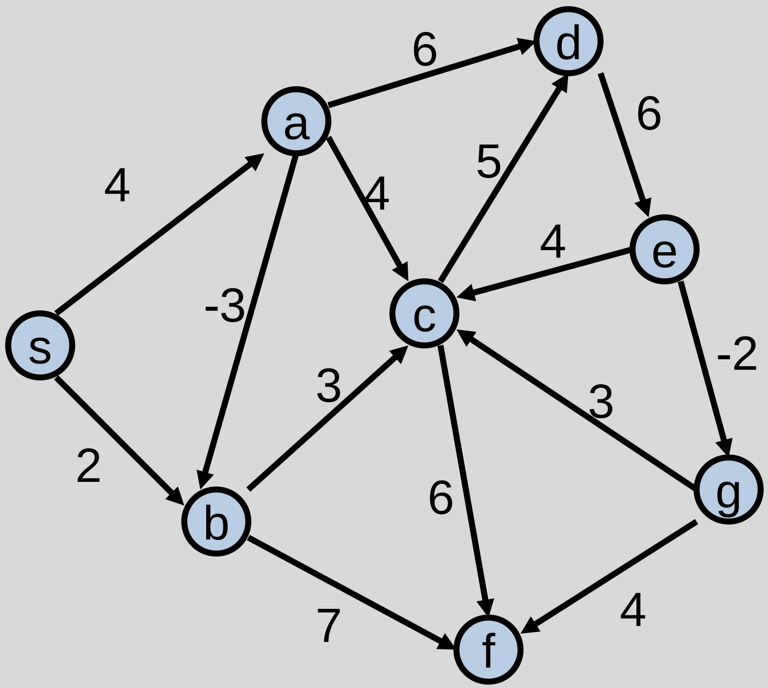
```
FOR i := 1 TO n
      d[i] := Infinity;  visited[i] := FALSE;
d[s] := 0;

FOR i := 1 TO n
      v := -1;  dMin := Infinity;
      FOR j := 1 TO n
            IF visited[j] = FALSE AND d[j] < dMin
                  v := j; dMin := d[j];
      IF v = -1
            RETURN;
      visited[v] := TRUE;

      FOR j := 1 TO n
            IF d[v] + len[v, j] < d[j]
                  d[j] := d[v] + len[v, j];
                  prev[j] := v;
```

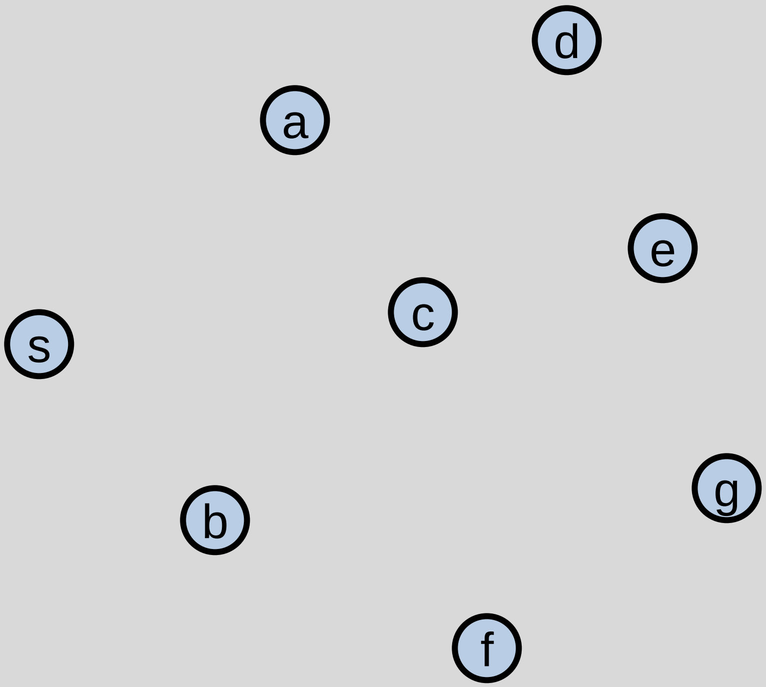
# Bottleneck Shortest Path

- Define the bottleneck distance for a path to be the maximum cost edge along the path



# Compute the bottleneck shortest paths



# How do you adapt Dijkstra’s algorithm to handle bottleneck distances

- Does the correctness proof still apply?